

# Measurements of top quark properties at CDF

Aafke Kraan (University of Pennsylvania)

On behalf of the CDF collaboration

ICHEP 26 July - 2 August 2006, Moskou



# Motivations

Why is it so important to study top quark properties?

- Top quark is a elementairy Standard Model particle!
  - Top mass is fundamental parameter ( $\sim 172$  GeV)
  - Is the top quark we observe really the Standard Model top?
  - Top properties could be modifies by new physics....
    - Top production: new resonances?
    - Top decay:
      - Is it  $t \rightarrow W^+ b$ ?
      - Is it a  $b$ ? Or is it a  $q$ ?
      - Is it a  $W^+$ ? Or a  $W^-$ ? Or is it a  $H^+$ ?
      - Is it a V-A weak decay?



Still relatively little is known about the top quark !

The Tevatron at Fermilab is the only place where top properties can be studied with high precision for the next 2-3(?) years!

# Top quark properties

3/11

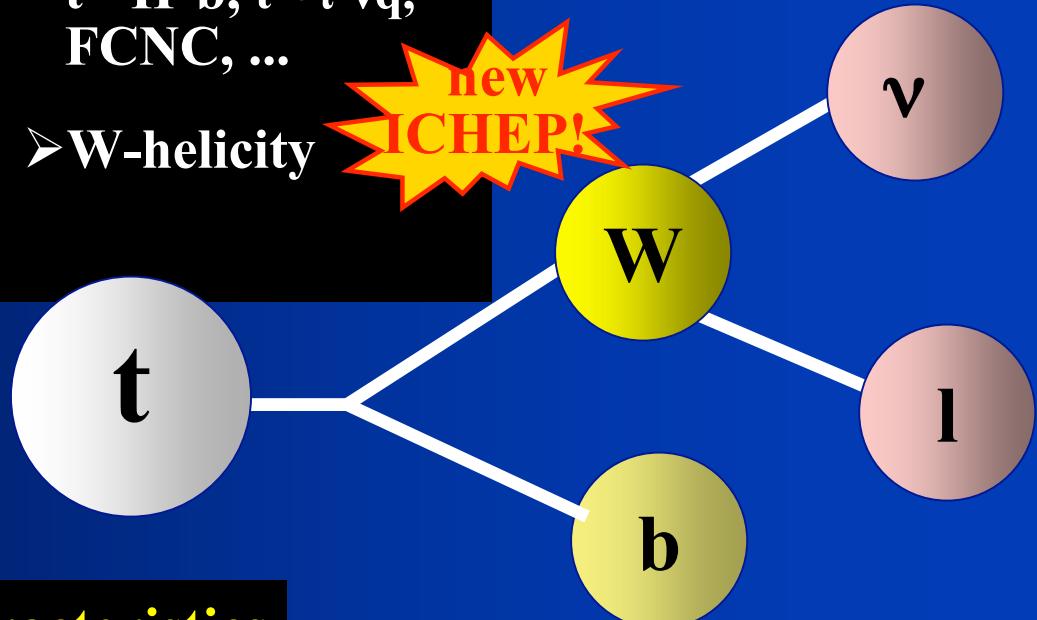
## Production:

- Single production\*\*\*
- Pair production
  - Cross sections\*
  - Mechanism
    - gg/ $q\bar{q}$ \*
    - Spin correlation
    - Resonances?

new  
2006

## Top quark decay

- $B(t \rightarrow Wb/t \rightarrow Wq)$
- Non SM decays:  
 $t \rightarrow H^+ b$ ,  $t \rightarrow \tau^- \nu_\tau$ ,  
FCNC, ...
- W-helicity



## Characteristics

- Mass \*\*
- Lifetime
- Spin
- Charge

\*: C. Hill, HQ  
\*\*: F. Canelli, EW  
\*\*\*: W.Wagner, EW

new  
2006

## This talk:

- New measurements!!
- Summary of other measurements.

new  
2006

# Top pair production: resonances?

4/11

- Motivation: Resonances predicted in models with dynamical EW symmetry breaking:[topcolor models Hill, Phys.Lett.B266, 418,1991]

Sample: lepton+jets  $\geq 4$  jets, 680 pb $^{-1}$   
no b-tagging.

## Method:

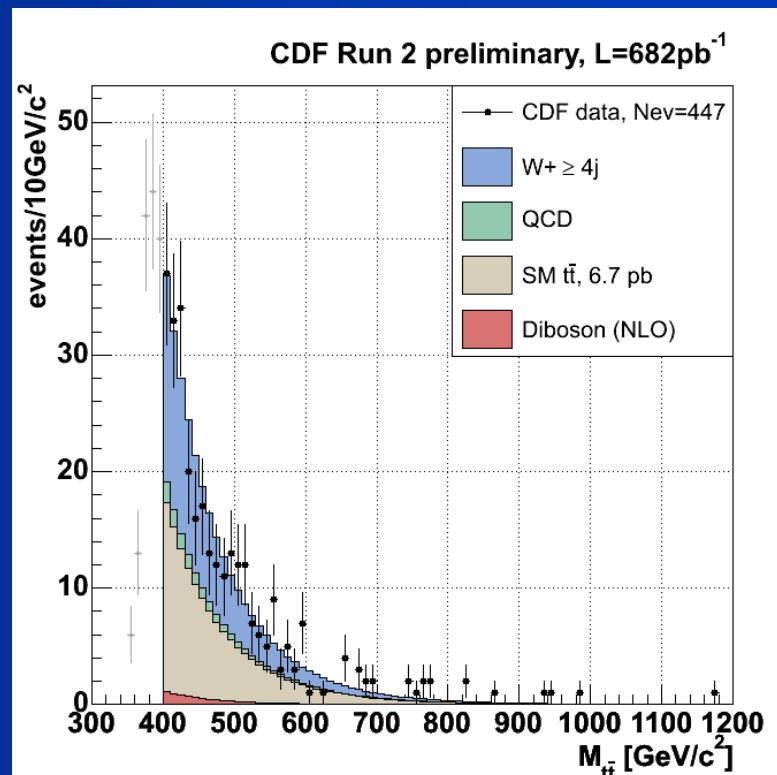
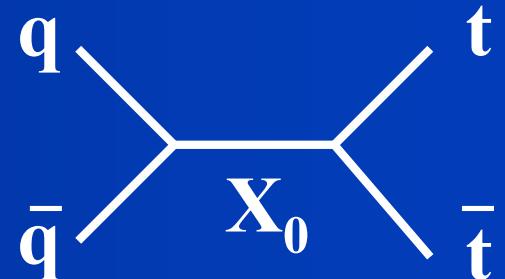
- Observable: invariant mass  $M_{t\bar{t}}$
- Use matrix element technique to assign for each event jets to partons

Result: No resonances seen...

Cross section limits set...

If  $X_0$ =leptophobic Z':  $M_X > 725$  GeV  
(Run1: 480 GeV)

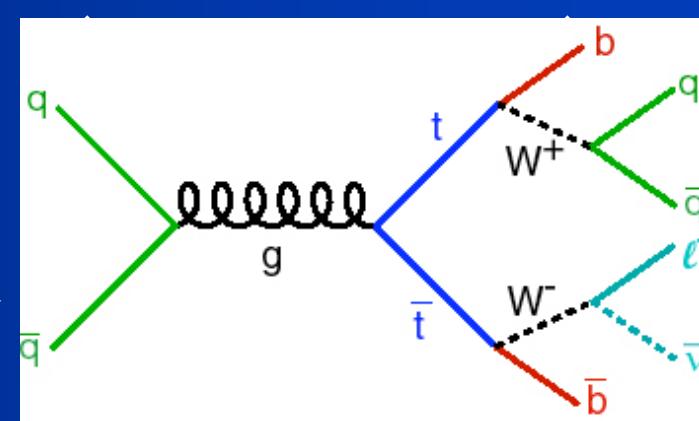
682 pb $^{-1}$



# Top decay: W-helicity

5/11

- Top quark decays via weak interaction to spin-1  $W^+$  boson and spin-1/2 b quark
- Weak interaction is V-A, so massless b-quark must be left-handed.



## W<sup>+</sup> boson helicities (J•P)

- J•P = 0: longitudinal
- J•P = -1: left-handed
- J•P = +1: right-handed

## V-A(SM)

$$\begin{aligned} f_0 &= 70\% \\ f_- &= 30\% \\ f_+ &= 0\% \end{aligned}$$

## V+A

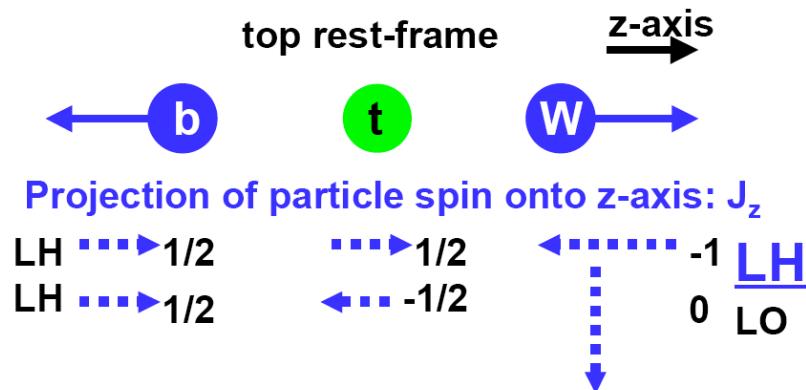
$$\begin{aligned} f_0 &= 70\% \\ f_- &= 0\% \\ f_+ &= 30\% \end{aligned}$$

## Motivation: is SM prediction modified beyond the standard model??

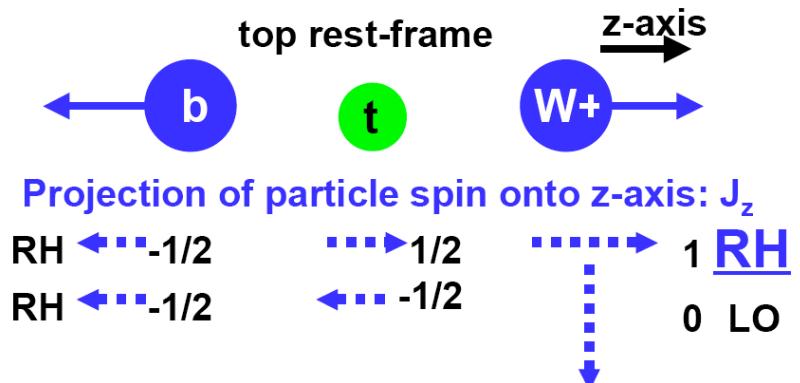
- Left-right symmetric models? Mirror fermions?

Models:	Kane,Yuan et al.: Beg, Mohapatra et al.: Triantaphyllou: Tait,Yuan, He et al.:	Phys.Rev.D45:1241,1992, Phys.Rev.Lett.38:1252, 1977. J.Phys.G26:99,2000, Phys.Rev.D62:011702,2000 Phys.Rev.D65:053002,2002
---------	---	--

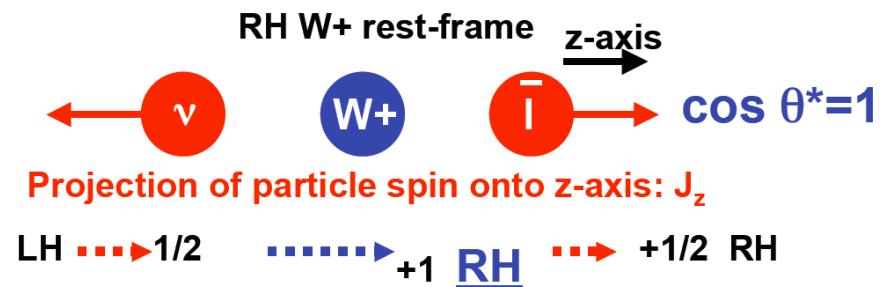
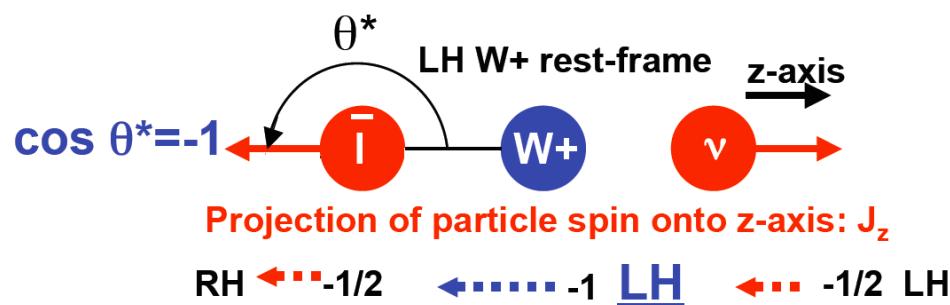
## V-A t-W-b vertex



## V+A t-W-b vertex



Assume nothing new in  $W^+ \rightarrow l^+ \nu$  decay: neutrino is left-handed



$\theta^*$  is polar angle of charged lepton in  $W$  boson rest frame.

The z-axis is defined by the  $W$  boson direction in top quark rest frame.

# W-helicity: analysis techniques

7/11

- Sensitive **observables** to W helicity are all from  $t \rightarrow W b \rightarrow l b$

## 1. Lepton $P_T$

**Sample:** lepton+jets  
dileptons

## 2. $M_{lb}^2$ : invariant mass squared of lepton and b-quark

**Sample:** lepton+jets  
dileptons

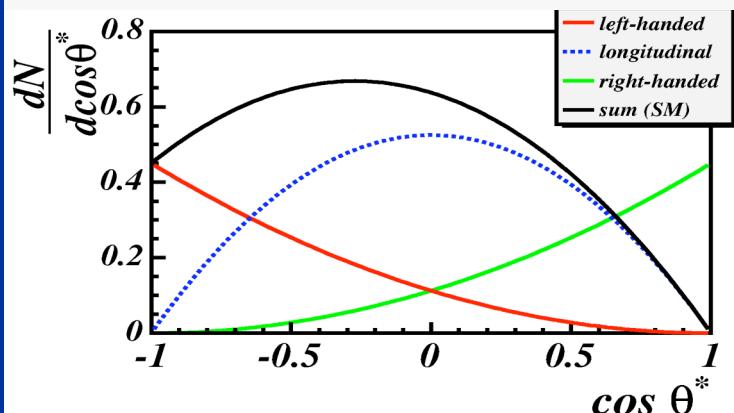
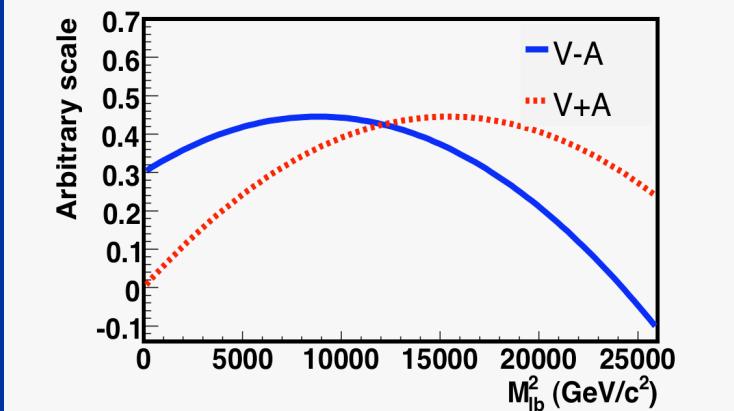
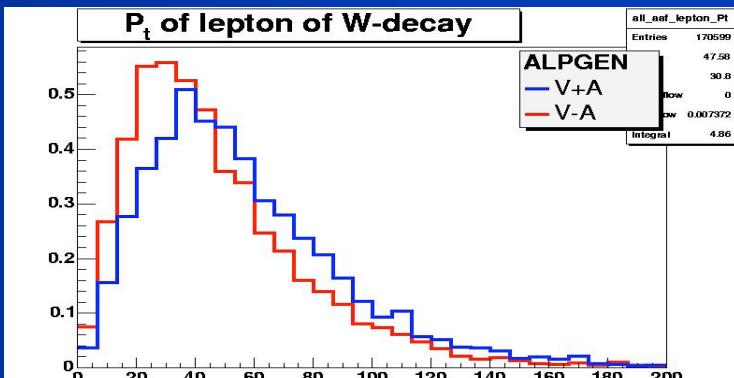
**Note:**

$$M_{lb}^2 = \frac{1}{2} (M_t^2 - M_W^2)(1 + \cos \theta^*)$$

## 3. $\cos \theta^*$ : reconstruct full ttbar event and boost to top and W rest frames

**Sample:** lepton+jets only

complexity



# W-helicity: $M_{lb}^2$ method

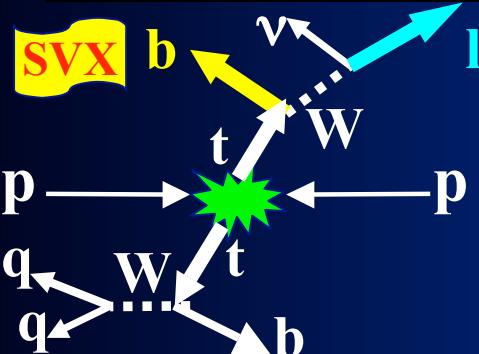
8/11



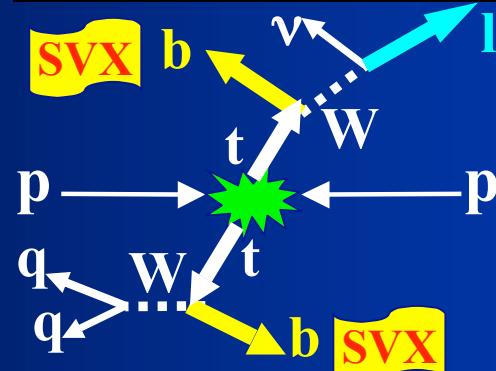
- Method: Use inv. mass squared of lepton+b-jet

## Samples:

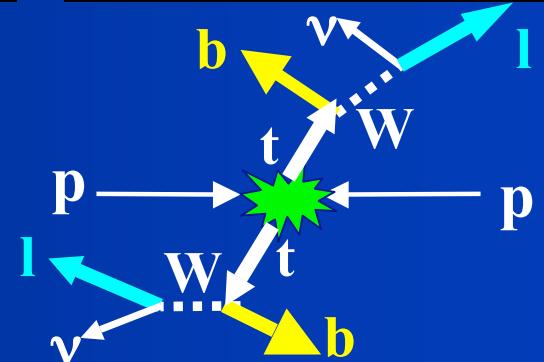
Lepton+ $\geq 3$  jets with  
1 b-tagged jet



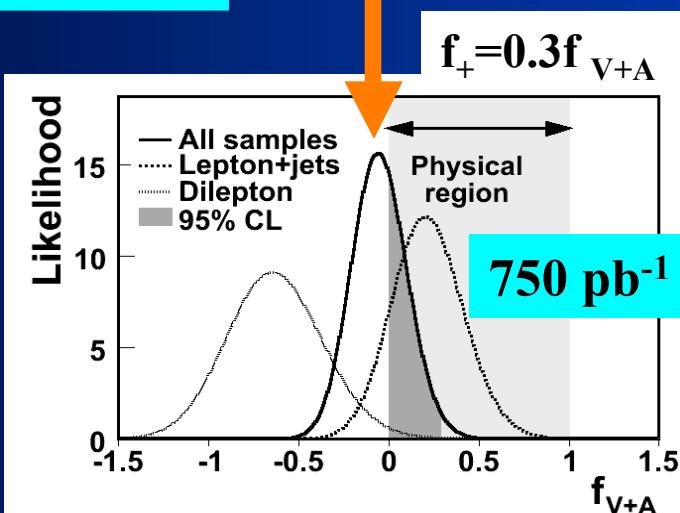
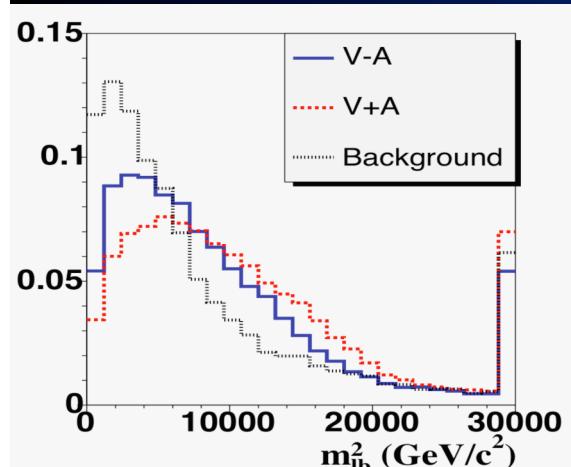
Lepton+ $\geq 3$  jets with  
2 b-tagged jets



Dilepton and 2 highest  
 $E_T$  jets (no b-tagging):



L+J 1b-tag after sim+reconstruction



## Result:

long.  $f_0 = 0.7$  fixed!

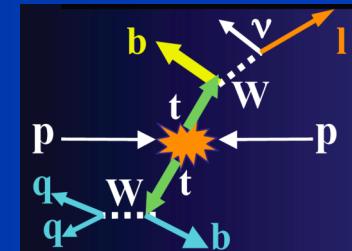
$f_+ = -0.02 \pm 0.08$

$f_+ < 0.09$  at 95% CL

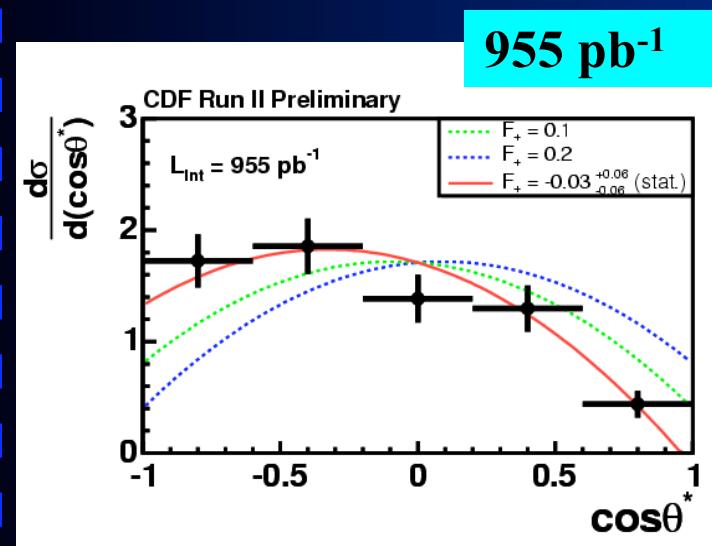


# W-helicity: $\cos\theta^*$ method

- Sample: Lepton+ $\geq 4$  jets + b-tagging
- Method: - Get  $\cos\theta^*$  from 4-vectors of lepton, W, top
  - Reconstruct fully top production+decay
  - Pick best hypothesis, based on:
- improved kinematic fitter for b-tagging



top mass kinematic fitter

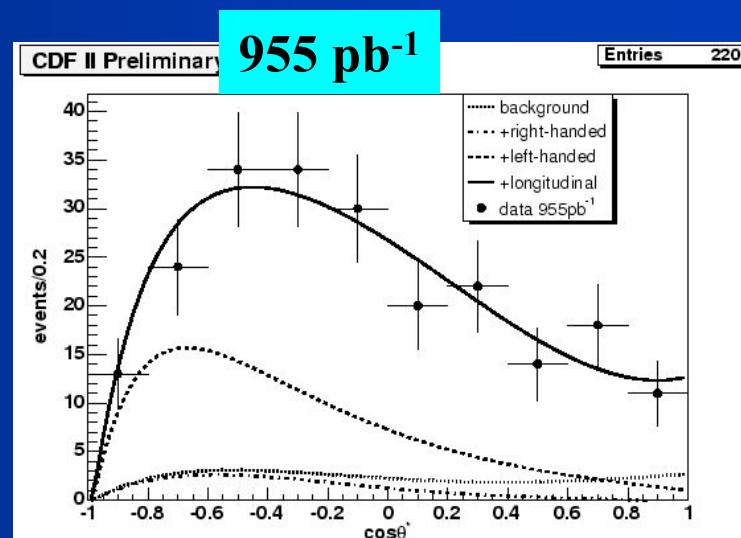


Result:

- $f_0 = 0.59 \pm 0.14$  with  $f_+ = 0$
- $f_+ = -0.03 \pm 0.07$  with  $f_0 = 0.7$
- $f_+ < 0.10$  @95% CL

Remember:

$$\text{SM: } f_0 = 0.7 \\ f_+ = 0$$



Result :

- $f_0 = 0.61 \pm 0.14$  with  $f_+ = 0$
- $f_+ = -0.06 \pm 0.07$  with  $f_0 = 0.7$
- $f_+ < 0.11$  @95% CL

# Top quark lifetime

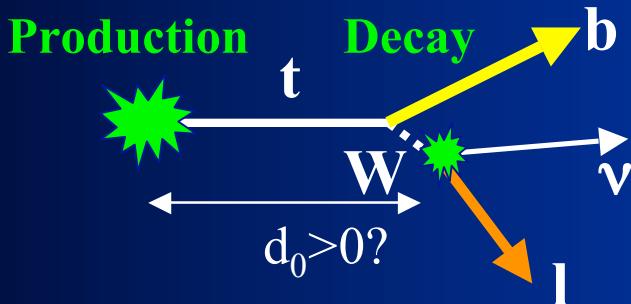
10/11

**Motivation:** top is heavy  $\rightarrow$  decays promptly: lifetime  $\tau = h/\Gamma_t \sim 10^{-25}$  s

First direct limit!

**Sample:** lepton+jets  $\geq 3$  jets + btagging,  $320 \text{ pb}^{-1}$

**Method:**

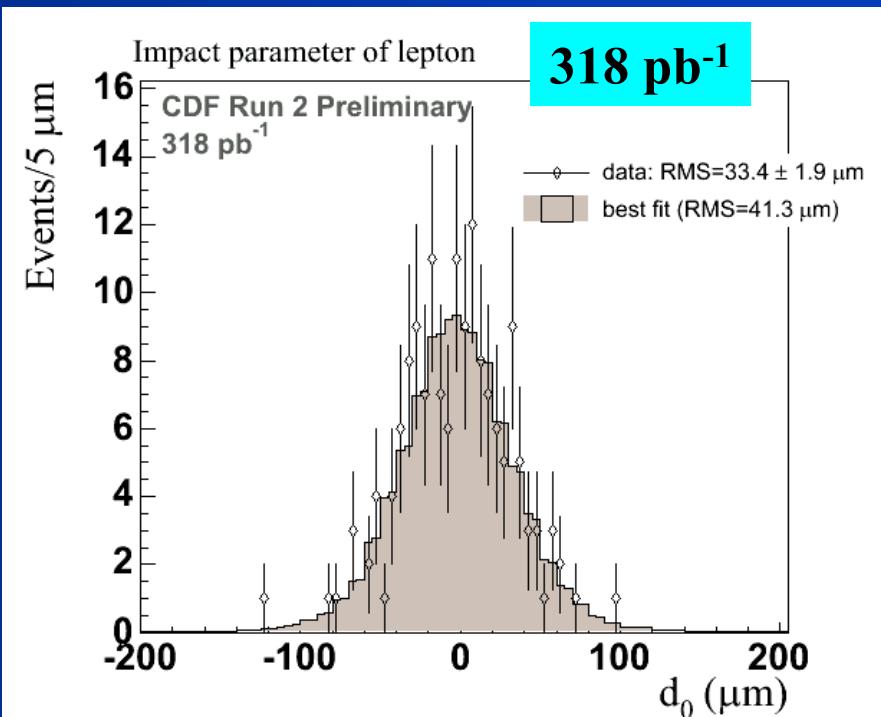


- › Determine resolution from lepton trigger data
- › Measure impact parameter  $d_0$  for lepton tracks in top data sample.

**Result:** Upper limit:

95% CL limit :

$$c\tau_t < 52.5 \mu\text{m} \sim 1.8 \times 10^{-13} \text{ s}$$



# Summary & plans

- High luminosity samples → very nice measurements possible!
- CDF+D0 are the only places for top data analyses for the next years!!

Property	Publication status	Luminosity ( $\text{pb}^{-1}$ )
$\text{Br}(t \rightarrow Wb / t \rightarrow Wq)$	PRL 95, 102002, 2005	162
Anomalous kinematics	PRL 95 022001, 2004	194
$t \rightarrow H^+ b$	PRL 96, 042003, 2005	194
$t \rightarrow \tau v q$	hep-ex/0510063, Apr 2006	350
<b>Top lifetime</b>	CDF-conf 8104, Feb 2006	320
Production gg/qq	CDF-conf XXX, July 2006	330
Search for $t'$	CDF-conf 8003, Mar 2006	760
<b>tt Resonances</b>	CDF-conf 8087, Mar 2006	680
<b>W-helicity</b>		
$M_{lb} + p_T^{\text{lepton}}$	PRD 73 111103	162+run1
$\cos \theta^*$	CDF-conf 8250, Apr 2006	320
$M_{lb}$	CDF-conf 8280, May 2006	750
$\cos \theta^*$	CDF-conf 8363, Jun 2006	955
Top charge	Result coming soon!	$1 \text{ fb}^{-1}$
FCNC	Result coming soon!	$1 \text{ fb}^{-1}$
Anomalous couplings	Result coming soon!	$1 \text{ fb}^{-1}$
Front/back asymmetry	Result coming soon!	$1 \text{ fb}^{-1}$

**Results/updates see** <http://www-cdf.fnal.gov/physics/new/top/top.html>

# $M_{lb}^2$ method: dileptons

12/11

